UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 5 Examination in Engineering: July 2017

Module Number: EE5304 **Module Name: Power Electronics**

[Three Hours]

[Answer **all questions**, each question carries 12.5 marks]

Q1 a) i) List three applications where phase controlled rectifiers are used.

ii) What is the advantage of using a thyristor bridge over a diode bridge?

iii) Sketch the power circuit of a single phase full bridge thyristor converter.

[3.0 Marks]

b) The AC side and the DC side of a single phase full bridge thyristor converter are connected to an AC source ($v_s = V_s \sin(\omega t)$) and inductive load, respectively. The firing angle (α) of the converter is within the range of ($0^0 < \alpha < 180^0$). Assume that the source inductance (L_s) is negligible.

i) Sketch the waveforms of the output voltage (v_d) and the input current (i_s) of the converter for three half-cycles of the AC source voltage and state which devices are conducting in each half cycle of the supply voltage.

ii) Plot the variation of the average output voltage (V_d) of the converter with α. Hence, indicate the quadrants of the $v_d - i_d$ plane in which the converter can operate and justify your answer using the plot drawn for V_d.

iii) Briefly explain the effect of the source inductance for the operation of a single phase full bridge thyristor converter.

[4.5 Marks]

c) The armature of a 4.0 hP separately excited DC motor is supplied by a power electronic (PE) system as illustrated in Figure Q1(c). The DC side and the AC side of the thyristor converter are connected to the DC motor and a 4.2 kVA, 50 Hz, single phase distribution transformer, respectively. The turns ratio of the transformer is 0.5 and it is supplying the rated load. It is found that the THD of the PE system is 48.43%. The parameters of the system components are listed in Table Q1(c) -1 and the IEEE harmonic guide lines are given in Table Q1(c)-2.

i) Clearly stating your assumptions, calculate the armature voltage (V_d) and the current (I_d) of the DC motor when it runs at the rated speed of 800 rpm.

ii) Clearly stating your assumptions, calculate the firing angle (α) of the converter.

iii) Calculate the voltage of the high voltage side and the low voltage side of the transformer under this condition.

iv) Is harmonic filtering (active filtering) required for this system? Justify your answer with necessary calculations.

[5.0 Marks]

Q2 a) i) Define the following terms associated with converters made of controllable switches.

I) Switching frequency (f_s)

II) Duty ratio (D)

ii) List three applications where DC-DC switch-mode converters are used.

[2.0 Marks]

b) i) Draw the power circuit of the buck-boost type DC-DC converter.

ii) Briefly explain the continuous-conduction mode, discontinuous-conduction mode and the critical condition of a DC-DC buck-boost converter.

iii) Clearly stating your assumptions, obtain the input/output voltage (V_{in}, V_o) and current (I_{in}, I_o) relationships in terms of D of the DC-DC buck-boost converter for the continuous-conduction mode.

iv) Derive expressions for the following terms associated with a DC-DC buck-boost converter.

I) The peak-peak inductor current ripple (Δi_L) in terms of L, V_o, D and f_s.

II) The average inductor current ($\overline{i_L} = I_L$) in terms of I_{in} and I_o.

III) The peak-peak output voltage ripple (ΔV_c) in terms of C, I_o, D and f_s.

[5.5 Marks]

c) Grid Integration of a proton exchange membrane fuel cell (PEMFC) stack is illustrated in Figure Q2(c). The PEMFC stack consists of 10 series connected PEMFCs each with internal resistance of 0.1 Ω. The average discharging current of a cell should be kept at 0.5 A. Due to the variation of the H_2 supply, the stack voltage is varying in a range from 90 V to 150 V. For each input value, the duty-ratio of the DC-DC converter is adjusted to keep the inverter input voltage constant at 120 V using PWM switching with $f_s = 25$ kHz.

i) What are the components of the power processor?

ii) What type of single-switch DC-DC converter is suitable for this application? Justify your answer.

iii) Calculate the variation of D of the converter for the whole range of PEMFC stack voltage.

iv) Calculate the critical inductance (L_{crit}) of the converter such that this converter remains in the continuous conduction mode at and above the output power of 50 kW.

[5.0 Marks]

Q3 a) i) Distinguish the main difference between full-bridge DC-DC converters over single switch DC-DC converters.

ii) Define the blanking time associated with the full-bridge DC-DC converter?

[3.0 Marks]

b) Consider the full-bridge DC-DC converter given in Figure Q3(b).

i) Briefly explain two PWM switching schemes that can be used for a full bridge DC-DC converter.

ii) Sketch the waveforms of v_{AN}, v_{BN}, v_O and i_o for three half cycles of the triangular signal, used in the PWM generator, indicating which devices are conducting, if the converter shown in Figure Q3(b) uses the PWM with bi-polar voltage switching.

iii) Using the waveforms drawn in part ii), show that the duty ratios (D_1) of the switch pair (T_{A+}, T_{B-}) can be expressed as,

$$D_1 = 1/2\left(1 + v_{control}/\hat{V}_{tri}\right)$$

Where $v_{control}$ and $\hat{V}_{tri}$ denotes the control voltage and the peak value of the triangular signal used in the PWM generator respectively.

iv) Hence, show that the average output voltage (V_o) can be deduced as,

$$V_O = V_d\left(v_{control}/\hat{V}_{tri}\right)$$

[4.5 Marks]

c) The armature of a 4.0 hP, 1500 rpm separately excited DC motor is supplied by a full bridge DC-DC converter as illustrated in Figure Q3(b). The armature inductance and the voltage constant of the DC motor are 1.5 mH and 0.11 V/rpm, respectively. The armature resistance is negligible. The input DC voltage to the converter is 300 V. If the converter uses the PWM with bi-polar voltage switching with the switching frequency (f_s) of 25 kHz and the DC motor runs its rated load,

i) Calculate D_1 of the switch pair (T_{A+}, T_{B-}) of the converter.

ii) Sketch the armature voltage v_a as a function of time for one switching cycle.

iii) Find the average, maximum and the minimum value of the armature current (i_a). Sketch i_a as a function of time for one switching cycle.

iv) Sketch the input current to the converter (i_d) for one switching cycle.

[5.0 Marks]

Q4 a) i) What is the function of an inverter?

ii) List three applications where inverters are used.

iii) What is the difference between voltage source inverters (VSI) and current source inverters (CSI)?

iv) Why is it necessary to connect diodes in anti-parallel with the controllable switches in switch mode inverter circuits?

[4.5 Marks]

b) A 480 V, 50 Hz, split phase single phase induction motor is supplied at the rated condition by a single phase full-bridge VSI through a low pass filter. The DC link of the VSI is kept at 850 V and the switches of the VSI are switched using uni-polar voltage switching with the switching frequency of 1.4 kHz.

i) Define the frequency modulation ratio (m_f) and the amplitude modulation ratio (m_a) of a VSI. Explain how these parameters are used in VSI operation.

ii) Calculate m_a and m_f of the VSI. Why is m_f chosen as an even number?

iii) Using Table Q4(b), compute the rms value of the five most dominant harmonics of the output voltage and the corresponding frequencies at which these harmonics appear.

iv) Suggest a suitable value for the cut-off frequency of the low pass filter in the motor drive. Justify your answer.

[5.0 Marks]

c) You are asked to generate the voltage waveform shown in Figure Q4 (c).

i) Using your knowledge on power electronic converters, draw a circuit which can generate the required voltage wave form.

ii) Explain how the circuit you have drawn functions.

[3.0 Marks]

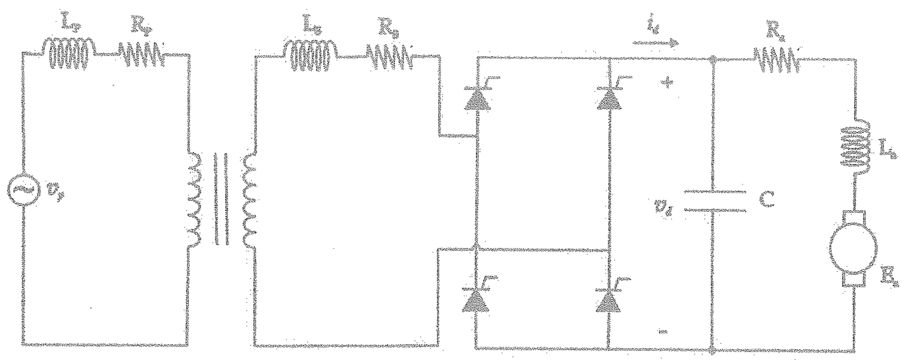

Figure Q1(c) PE system

Table Q1(c)-1 : Parameters of the PE system

$R_p = 0.05\ \Omega$	$R_s = 2\ \Omega$	$R_a = 0.18\ \Omega$
$X_p = 0.06\ \Omega$	$X_s = 2\ \Omega$	$L_a = 5$ mH
$R_c = 300$ kΩ	$X_m = 30$ kΩ	$k_t = 3.58$ V/rads^{-1}

Table Q1(c)-2 : IEEE harmonic guide lines

I_{SC}/I_{S1} (The ratio of the rated short circuit current of the supply to the fundamental current of the PE system)	THD (%)
20 >	5
20 - 50	8
50 - 100	12
100 - 1000	15
> 1000	20

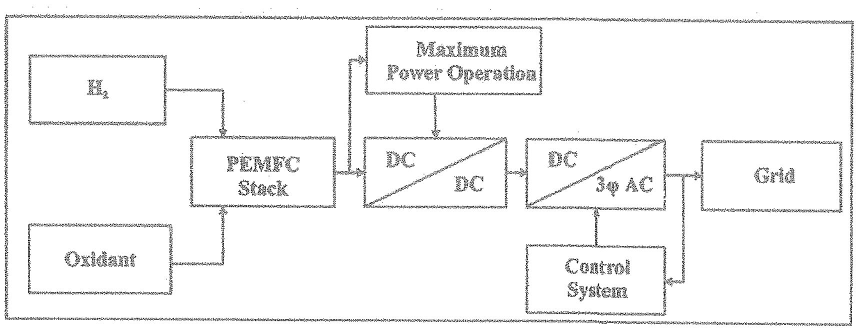

Figure Q2(c) Grid integration of PEMFC stack

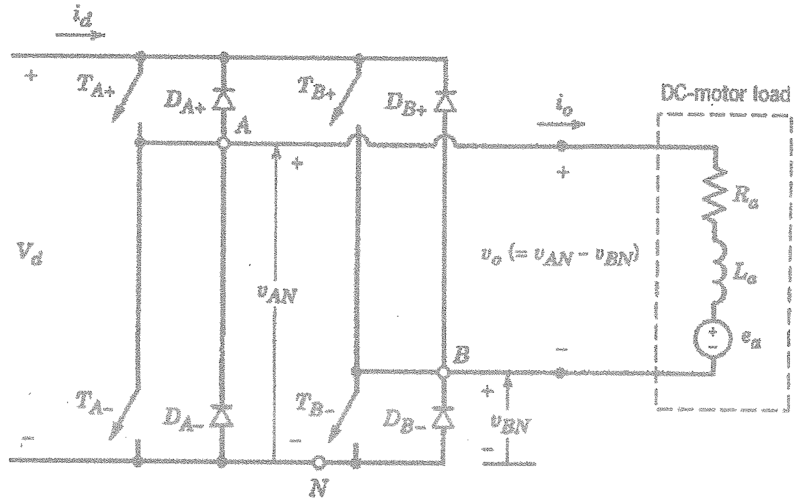

Figure Q3(b) DC-DC full-bridge converter connected with a DC motor

Table Q4(b) Generalized harmonics ($\hat{V}_{Ao}/(V_d/2)$) for large m_f

h \ m_a	0.2	0.4	0.6	0.8	1.0
1 Fundamental	0.2	0.4	0.6	0.8	1.0
m_f	1.242	1.15	1.006	0.818	0.601
$m_f \pm 2$	0.016	0.061	0.131	0.220	0.318
$m_f \pm 4$					0.018
$2m_f \pm 1$	0.190	0.326	0.370	0.314	0.181
$2m_f \pm 3$		0.024	0.071	0.139	0.212
$2m_f \pm 5$				0.013	0.033
$3m_f$	0.335	0.123	0.083	0.171	0.113
$3m_f \pm 2$	0.044	0.139	0.203	0.176	0.062
$3m_f \pm 4$		0.012	0.047	0.104	0.157
$3m_f \pm 6$				0.016	0.044
$4m_f \pm 1$	0.163	0.157	0.008	0.105	0.068
$4m_f \pm 3$	0.012	0.070	0.132	0.115	0.009
$4m_f \pm 5$			0.034	0.084	0.119
$4m_f \pm 7$				0.017	0.050

where $\hat{V}_{Ao}$ is the peak value of the output of the one-leg inverter.

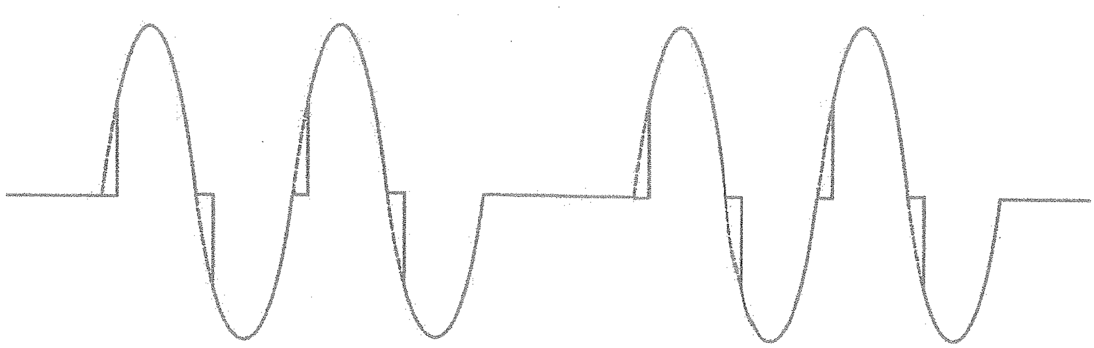

Figure Q4 (c)